Using the Triangulation Method to Measure the Distance to Objects in the Working Area of a Collaborative Manipulator Robot

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Abstract**:** This report considers the use of the triangulation method to measure the distance to objects in the working area of a collaborative manipulator robot. The proposed approach provides high accuracy and speed of determining the positions of objects, which is critically important for safe and efficient performance of tasks. The use of triangulation allows robots to adapt their actions to changing environmental conditions, helping to increase productivity and reduce risks. The results of the study confirm the importance of the triangulation method as an important tool for the integration of robotic systems into modern production processes.

Keywords**:** Industry 5.0, Collaborative manipulator robots, distance measurement, triangulation method.

I. Introduction

In the context of the concept of Industry 5.0, which emphasizes the harmonization of cooperation between people and robots, the use of the triangulation method to measure the distance to objects in the working area of a collaborative robot-manipulator acquires special importance. This method provides high accuracy in determining the positions of objects, which is critical for the safe and efficient performance of tasks. Triangulation allows robots to adapt their movements to changing environmental conditions, helping to increase the efficiency of production processes. The relevance of this study lies in the need to integrate the latest technologies to improve the interaction between people and robots, which is the basis for the implementation of the principles of Industry 5.0. Thanks to the use of triangulation, collaborative robots can more accurately assess their capabilities, which allows to reduce the risk of errors and ensure higher productivity. In today's environment, where speed and accuracy are the determining factors of success, the introduction of such technologies has the potential to significantly change approaches to automation. Therefore, the study of distance measurement methods, in particular triangulation, becomes an integral part of the development of innovative solutions for robotic systems within the framework of Industry 5.0.

II. COMPUTER VISION MODEL FOR ENVIRONMENTAL OBSERVATION

The triangulation method based on two HC-SR04 ultrasonic sensors can be used to determine the position of an object in the working area of a collaborative robot-manipulator. This approach allows you to obtain two-dimensional or three-dimensional coordinates of an object by measuring the distances from two known points to the object, which makes it useful for creating a dynamic model of the robot's working environment, according to the concepts of Industry 5.0.

Triangulation is based on measuring distances from two or more points to an object and then calculating the coordinates of this object in space. In the case of the two HC-SR04 ultrasonic sensors, each of them measures the distance to the object, and these distances are used to determine the coordinates of the object in 2D space.

Suppose that two ultrasonic sensors are located at known positions (x_1, y_1) and (x_2, y_2), and the measured distances to the object are d_1 and d_2.

Then the object is located at the intersection of two circles, the radii of which correspond to the measured distances from each sensor to the object:

- d_1 – distance from the first sensor to the object,
- d_2 – distance from the second sensor to the object.

The equations for calculating object coordinates based on the intersection of circles are as follows:

$$\begin{aligned}(x-x_1)^2 + (y-y_1)^2 &= d_1^2\\ (x-x_2)^2 + (y-y_2)^2 &= d_2^2.\end{aligned} \tag{1}$$

The solution of this system of equations allows you to get the coordinates of the object (x, y).

To find a solution to (1), you can use geometric or numerical methods. One of the approaches is to solve the system of equations analytically, by substitution and simplification, which will give such possible values of the coordinates for the object.

It is suggested to use the following steps:

- take the system of equations for two circles;
- subtract the second equation from the first, which will get rid of quadratic terms;
- a simplified linear expression can be solved with respect to x or y, and then substitute the found value into one of the original equations to find other coordinates.

After simplification, we get a linear equation:

$$\begin{aligned}&2(x_2 - x_1)x + 2(y_2 - y_1)y =\\ &= d_1^2 - d_2^2 - (x_2^2 - y_2^2) + (x_1^2 - y_1^2).\end{aligned} \tag{2}$$

This equation can be solved relatively x and y.

For triangulation simulation based on two ultrasonic sensors, the following parameters are important:

- sensor coordinates (x_1, y_1, x_2, y_2) – are fixed points in space where HC-SR04 sensors are installed. The distance between them is also important for triangulation accuracy;
- measurement time, this is the signal transit time between the sensor and the object, on the basis of which the distance is calculated;
- speed of sound (v) – 343 m/s at room temperature is accepted as standard;
- radii (d_1, d_2) – are the distances from each sensor to the object, which are calculated based on the signal time.

We will give an example of a program implementation in Python, which allows you to calculate the position of an object in 2D space based on the measured distances from two HC-SR04 sensors.

```
import math
# Coordinates of two ultrasonic sensors
x1, y1 = 0, 0 # first sensor at position (0, 0)
x2, y2 = 10, 0 # second sensor at position (10, 0)
# Measured distances to the object (d1 and d2)
d1 = 7.0 # Distance from the first sensor to the object
d2 = 5.0 # Distance from the second sensor to the object
# Solving the system of equations to determine (x, y)
# Calculate x and y analytically
def calculate_position(x1, y1, x2, y2, d1, d2):
 A = 2 * (x2 - x1)
 B = 2 * (y2 - y1)
 C = d1**2 - d2**2 - (x1**2 + y1**2) + (x2**2 + y2**2)
 # Simplification for finding coordinates
 if B != 0:
 y = C / B
 x = math.sqrt(d1**2 - (y - y1)**2) + x1
 otherwise:
 x = C / A
 y = math.sqrt(d1**2 - (x - x1)**2) + y1
 return x, y
# Call the function to calculate the coordinates of the object
x, y = calculate_position(x1, y1, x2, y2, d1, d2)
print(f"Object coordinates: x = {x}, y = {y}")
```

Let's conduct an experiment using the triangulation method based on two HC-SR04 ultrasonic sensors and estimate the measurement error, let's define the main parameters, the experiment plan and the method of calculating the error.

The purpose of the experiment: to determine the distance to the object using two HC-SR04 ultrasonic sensors using the triangulation method, as well as to estimate the measurement error at different distances.

Experimental setup: two HC-SR04 sensors are installed at known fixed positions at a distance of L=10 cm from each other; the object is placed at different distances from the sensors along the x-axis (for example, 50 cm, 100 cm, 150 cm, 200 cm); For each position of the object, the distances d_1 and d_2 rom the sensors to the object are measured.

Steps of the experiment:

- place two HC-SR04 ultrasonic sensors at known coordinates $(x_1, y_1) = (0,0)$ and $(x_2, y_2) = (10,0)$;
- place the object in four different positions (50 cm, 100 cm, 150 cm, 200 cm from the sensor axis);
- measure distances for each position d_1 and d_2 using both sensors;
- using the triangulation method, calculate the real coordinates of the object x, y;
- determine the measurement error (ϵ) based on the calculated and real values of the distances. The error is calculated using the formula:

$$\epsilon = L_2 - L_1, \quad (3)$$

where L_2 – measured value, and L_1 – actual distance.

The measurement results obtained during the experiment are presented in Figure 1.

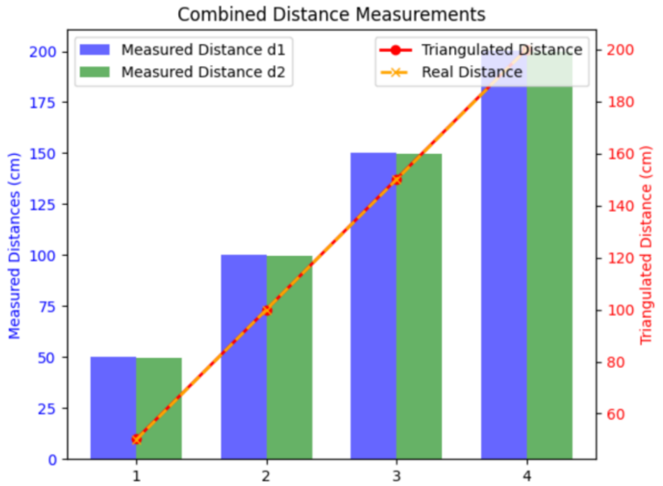

Figure 1 – Graph

As can be seen from the table, the measurement error is no more than 0.2 cm, which is consistent with the technical error of the HC-SR04 ultrasonic sensors. Since the accuracy of the sensors is ±3 mm (0.3 cm), the values obtained are within the permissible error.

III. Conclusion

In the context of Industry 5.0, collaborative work should have a high level of interaction with people and the environment. The use of triangulation allows you to create more adaptive and intelligent systems that can not only accurately determine the position of objects in the working area, but also dynamically respond to changes in the environment.

Thus, the method of triangulation based on ultrasonic sensors is an important tool for creating intelligent, dynamic systems of interaction between robots and the working environment in the context of Industry 5.0.

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